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PRE-MINING GROUND STRESSES AT THE DOME MINE, SOUTH PORCUPINE

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AUGUST 1988

19 pp

MINING RESEARCH LABORATORIES
DIVISION REPORT MRL 88-87 (TR)

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B. Arjang*

ABSTRACT

In the context of CANMET's regional mine stability project, pre-mining ground stresses were determined at the Dome Mine, Timmins mining district. The results of stress determinations carried out at depths of 438, 937 and 1238 m below surface indicate the following stress regime.

Maximum horizontal compressive stress is oriented ENE-WSW with an average gradient of 0.0441 ± 0.0027 MPa/m, and minimum horizontal compressive stress is in NW-SE direction with an average gradient of 0.0336 ± 0.0054 MPa/m. Stress directions show a gradual, clockwise rotation by about 10 to 40° with increasing depth. Stresses in the horizontal plane are close to isotropic, with the minimum horizontal stress being on average 76% of the maximum horizontal stress. The vertical stress component resulted in an average gradient of 0.0274 ± 0.0042 MPa/m.

In general, steeply dipping lenticular orebodies reveal an east-west trend at the mine. This suggests that the maximum horizontal compressive stress is aligned on-strike, while the minimum horizontal compressive stress acts perpendicular to the orebodies.

Variations of horizontal and vertical stresses as a function of depth are within the range of data observed in deep hard rock mines in Northern Ontario.

Key words: Overcoring strain recovery measurement: Pre-mining stress: Stress gradient.

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DÉTERMINATION DES CONTRAINTES NATURELLES AVANT LE DÉBUT DE L'EXCAVATION À LA MINE DOME, SOUTH PORCUPINE

B. Arjang*

RÉSUMÉ

Dans le cadre du projet de CANMET concernant la stabilisation du sol dans les mines à l'échelon régional, les contraintes naturelles ont été déterminées avant le début de l'excavation à la mine Dome, district minier de Timmins. Les résultats de la détermination des contraintes effectuée à des profondeurs de 438, 937 et 1,238 m sous la surface ont dénoté l'existence du régime de contraintes dont la description suit.

Sur le plan horizontal, la contrainte de compression maximale est en direction E.N.-E. - O.S.-O. et le gradient moyen est de 0,0441 + 0,0027 MPa/m. La contrainte de compression minimale sur le plan horizontal est en direction N.-O. - S.-E. et son gradient moyen est de 0,0336 + 0,0054 MPa/m. La direction que suivent les contraintes dénote une rotation graduelle d'environ 10 à 40°, dans le sens des aiguilles d'une montre, à une profondeur croissante. Les contraintes sur le plan horizontal sont presque isotropes, la contrainte minimale sur la plan horizontal équivalant en moyenne à 76 % de la contrainte maximale sur le plan horizontal. Le gradient moyen de la composante de la contrainte sur le plan vertical à été de 0,0274 + 0,0042 MPa/m.

De façon générale, une étude des corps de minerai lenticulaires à pendage raide révèle que les contraintes du sol de la mine ont tendance à se produire en direction est-ouest. Cette tendance indique que la contrainte de compression maximale sur la plan horizontal se manifeste le long du corps de minerai tandis que la contrainte de compression minimale est perpendiculaire à celui-ci.

Les variations des contraintes sur les plans horizontal et vertical en fonction de la profondeur se situent dans la gamme de données recueillies dans les mines de roche dure dans le Nord-Ontario.

Mots-clé : Mesure de la réduction de la déformation due au surcarottage; contraintes naturelles avant l'excavation; gradient de contraintes.

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INTRODUCTION

Pre-mining ground stress measurements were carried out at the Dome Mine. South Porcupine. following a request from Dome Mines Ltd. The underground stress determination was performed in the context of the regional mine stability project of CANMET.

The results of overcoring strain recovery measurements. carried out at three mine levels will assist the mine design and the stability evaluations of underground openings.

GEOLOGICAL SETTING

The Dome Mine is located in the Timmins mining district. Northern Ontario. The mine is situated on the south limb of the northeast plunging Porcupine syncline in an area where volcanic rocks are overlain by metamorphosed slate and conglomerate. as shown in Figure 1 (1). Major structural features are east-northeast and northerly trending fault zones. and locally well pronounced east-west oriented schistosity.

The long. narrow or lenticular veins and mineralized zones occur in a number of different massive or schistose rock types associated with various structural settings (2). In general. east-west trending and steeply dipping orebodies are aligned with the main trend of the formations. as well as massive flows. Figure 2 illustrates the generalized geological setting and a section of the mine.

STRESS MEASUREMENT SITES

The stress measurement sites were selected on the 12. 23 and 30 levels. 438 m. 937 m and 1238 m below surface. respectively. At all three sites the horizontal test holes were drilled perpendicular to the main structural trend

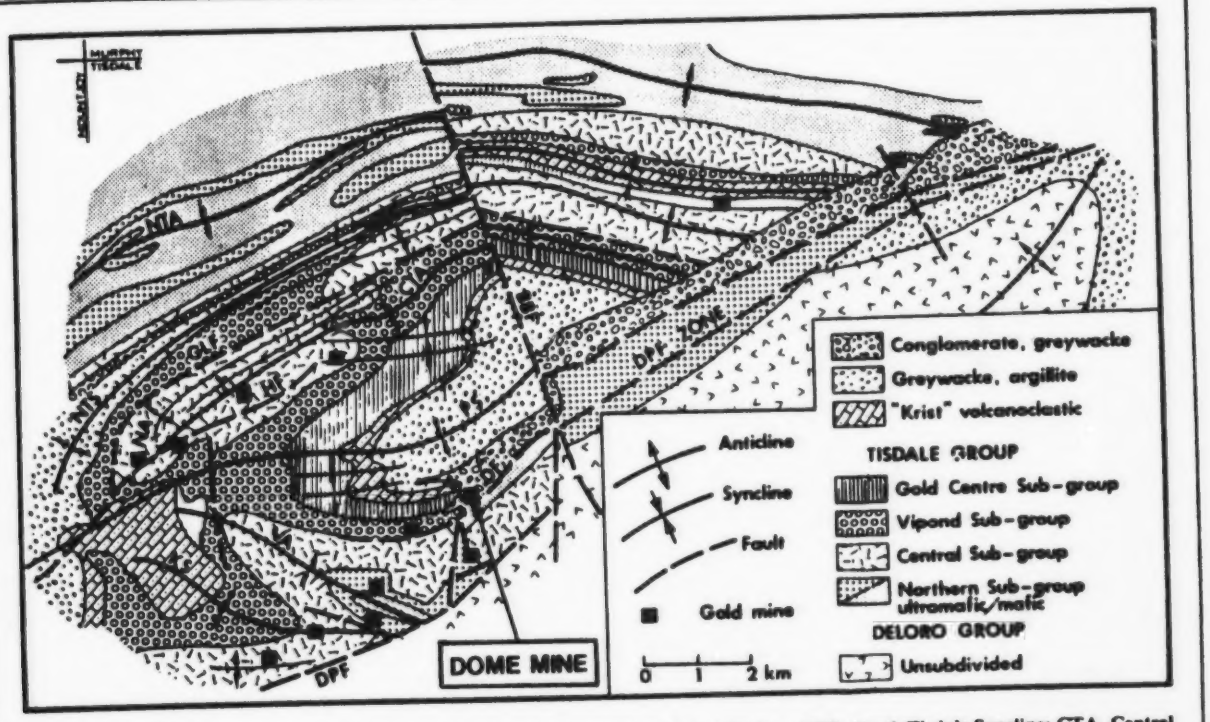

FIGURE 1. Geology and structure of the Timmins district. (NTA, North Tisdale Anticline; NTS, North Tisdale Syncline; CTA, Central Tisdale Anticline; PS, Porcupine Syncline; VA, Vipond Anticline; KS, Kayorum Syncline; GLF, Gillies Lake Fault; HF, Hollinger Fault; DF, Dome Fault; DPF, Destor-Porcupine Fault; BBF, Burrows-Benedict Fault).

Fig. 1 - Geology and structure of the Timmins district and the location of Dome Mine (1).

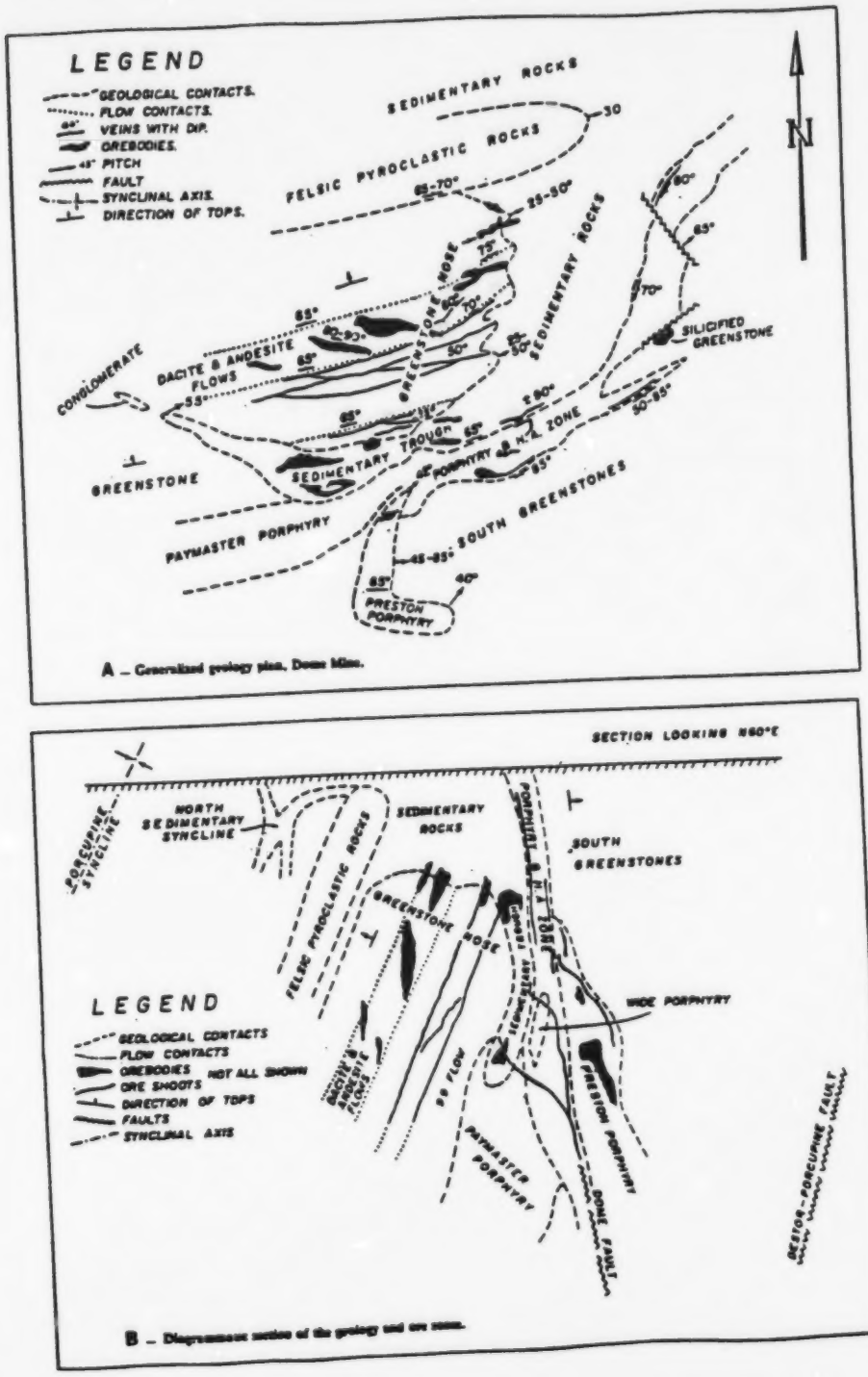

Fig. 2 – A) Generalized geology, and B) diagrammatic section of Dome Mine (2).

and the schistosity. In the vicinity of the measurement sites no major structural weakness plane was exposed. The location and direction of the test holes are shown in Figure 3. Overcoring strain recovery measurements using CSIR triaxial strain cells were taken in a fine-medium grained, partly chloritic porphyry and 'greenstone' rocks. Measurements were commenced at distances greater than 3.0 m from the wall of the development drifts, which were about 2.5 m square on the 12 and 23 levels, and 2.5 m x 6.0 m on the 30 level. A total of eight overcoring measurements was attempted, resulting in two successful measurements at each site.

Test holes with a nominal 153 mm diameter yielded 144 mm diameter cores. The large core size reduced the risk of core breakage in a highly schistose and low strength rock type. An average uniaxial compressive strength of 114 $\pm$ 15 MPa was determined on EX-size cores from the pilot holes at the stress measurement sites.

On the 30 level, the first drill hole had to be abandoned at a depth of 6.50 m because of continuous core breakage along the closely spaced fractures and the pronounced foliation planes. In addition, the varying strength of the rocks as well as the fracture zones resulted in the deviation of the drill hole.

In the abutment of 2415 stope at a depth of about 945 m, biaxial in situ stresses were measured using USBM gauges (3). The results are partly incorporated in the following stress calculations.

RESULTS OF STRESS DETERMINATIONS

The elastic strain recoveries and the strain invariances for the individual measurements are given in Table 1. The elastic constants for the rocks intersected in the test holes were determined from the uniaxial compression testing of solid and overcored hollow cylinders containing the

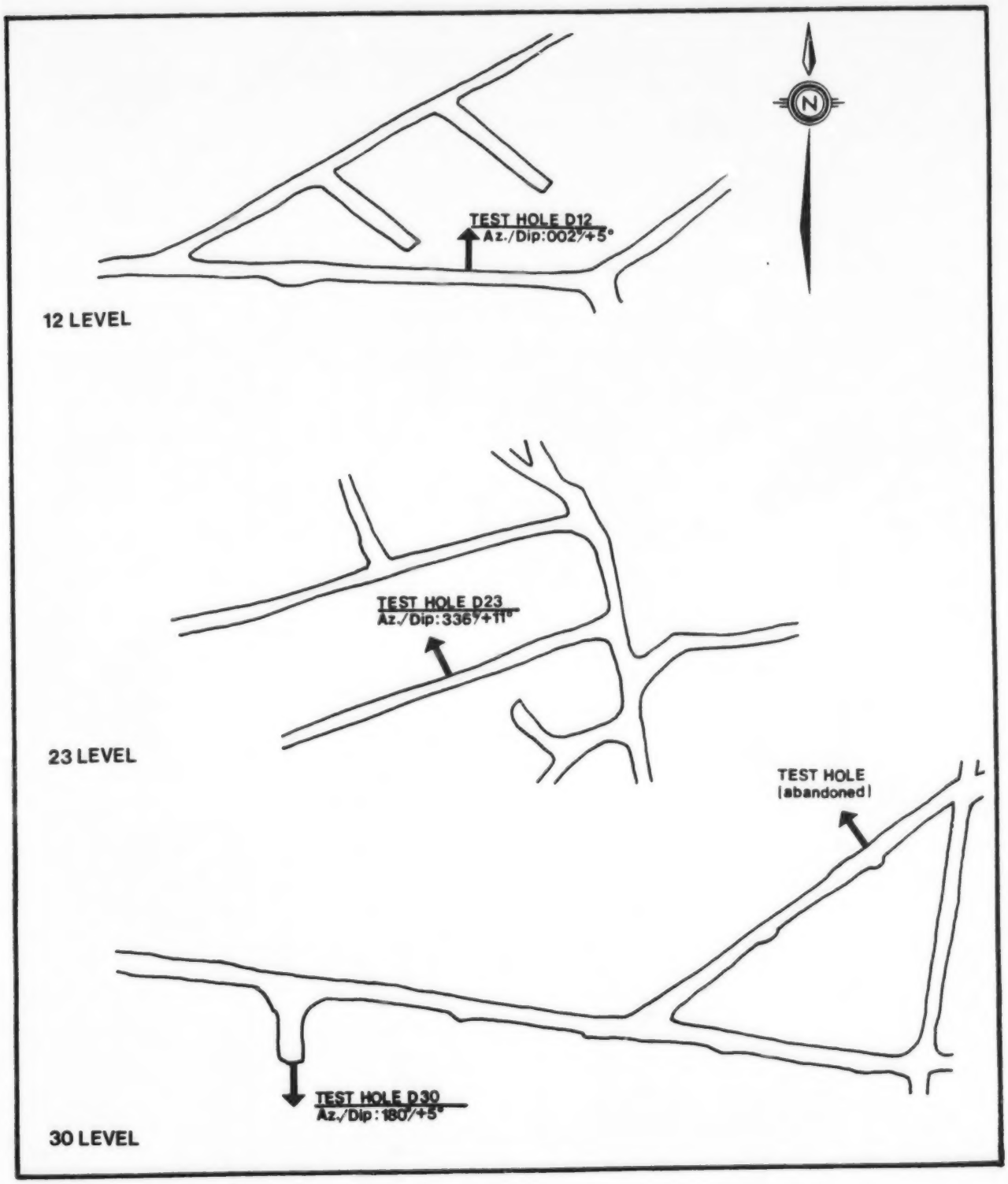

Fig. 3 - Stress determination sites and test hole locations on the 12, 23 and 30 levels (not to scale).

Table 1 - Strain recovery from triaxial strain cell measurements

Location (Depth)	Test No.	Test Depth (m)	Gauge No.: Elastic Strain Recovery ($x10^{-6}$) 1	2	3	4	5	6	7	8	9	10	11	12	SI(*) Rosette No. 1	2	3
12 level	D12-1	3.40	265	65	120	350	430	345	140	250	480	445	150	185	30	25	0
(438 m)	D12-2	4.00	Test not successful, overcored specimen fractured														
	D12-3	5.20	205	35	130	310	495	540	130	35	660	580	145	220	10	50	5
23 level	D23-1	3.20	510	140	60	405	1245	720	80	645	1195	720	60	490	25	40	45
(937 m)	D23-2	3.65	560	70	125	575	860	490	-20	360	1560	1000	85	625	40	10	20
30 level	D30-1	4.50	275	455	130	50	1480	775	170	820	1435	670	170	875	85	55	60
(1238 m)	D30-2+	5.15	775	950	650	465	655	705	355	435	390	590	665	365	10	130	100
	D30-3	5.70	425	540	285	155	1465	680	300	1070	1200	755	280	770	15	15	45

(*) Strain invariance (sum of strains in two orthogonal directions, $\varepsilon_1 + \varepsilon_3 = \varepsilon_2 + \varepsilon_4$).

(+) Test No. D30-2: oversized EX-pilot hole resulted in poor bonding of the strain cell, test excluded from stress tensor calculations.

strain cells. The results are given in Table 2. For the stress tensor calculations of individual sites, the mean values for the elastic modulus and Poisson's ratio were used.

Table 3 provides the results of stress determinations. The stress components in horizontal and vertical directions, and the direction of principal compressive stresses, are related to the mine coordinate system (Mine grid north = geographic north). Stress tensor calculations show errors in the range of 0.17 to 2.98 MPa for the stress components, corresponding to 1 to 20% of the magnitudes determined.

Figure 4 illustrates the orientation of the maximum (σ_1), intermediate (σ_2), and minimum (σ_3) principal compressive stresses, as well as the prevailing direction of σ_1 and σ_2. The orientation of stresses indicates that σ_1 and σ_2 are nearly horizontal, prevailing ENE-WSW and NW-SE directions, respectively, whereas σ_3 is oriented near vertical. On the 23 level, however, some deviations were observed, where σ_2 plunges vertically and σ_3 is sub-horizontal. Generally, for each stress determination site, good correlation exists between the directions as well as the magnitudes of measured stresses. The overall directions for the maximum and intermediate principal stresses were as follows:

Location	Depth	Principal Stress	
		Maximum	Intermediate
12 level	438 m	232°/horizontal	128°/horizontal
23 level	937 m	241°/horizontal	136°/sub-vertical
30 level	1238 m	261°/horizontal	171°/horizontal

The above angular differences in stress directions indicate that a gradual increase in the order of 10-40° exists with increasing depth. A clockwise rotation in the direction of maximum principal stress occurs from NE

Table 2 - Determination of elastic modulus (E). and Poisson's ratio (v) from uniaxial compression tests.

Location	Test No.	Core Specimen Height (mm)	Dia. (mm)	Ratio Height/ Dia.	E (GPa)	v	Rock Type
12 level:	D12-A	218	142	1.53	62.41	0.23	Porphyry
	D12-B	264	142	1.86	62.14	0.22	"
	D12-C	230	142	1.62	54.83	0.27	"
				Mean:	58.79	0.24	
				Std. Dev.	±4.30	±0.02	
23 level:	D23-1	320	142	2.25	68.27	0.31	'Greenstone'
	D23-A	358	142	2.52	55.72	0.28	"
	D23-B	297	142	2.10	66.07	0.27	"
				Mean:	63.35	0.28	
				Std. Dev	±6.70	±0.02	
30 level:	D30-1	258	142	1.81	68.27	0.28	'Greenstone'
	D30-3	330	142	2.32	69.65	0.32	"
	D30-A	265	142	1.86	61.17	0.26	"
	D30-B	285	142	2.00	63.45	0.30	"
				Mean:	65.63	0.29	
				Std. Dev.	±3.99	±0.02	

Table 3 - Stress components and principal compressive stresses from field stress determinations (stress in MPa).

Location (Depth)	Test No.	Stress Components (Standard errors in brackets) σ_{EW}	σ_{NS}	σ_v	τ_{EN}	τ_{NV}	τ_{VE}	STDV Std. (Error)+	Principal Compressive Stresses σ_1	σ_2	σ_3
12 level (438 m)	D12-1	15.8 (0.49)	14.3 (0.30)	12.3 (0.30)	1.06 (0.22)	3.93 (0.22)	0.65 (0.17)	0.11 (3%)	18.0 215/32*	15.1 113/18	9.2 358/52
	D12-3	19.0 (2.98)	14.3 (1.82)	12.4 (1.82)	-1.32 (1.05)	5.86 (1.38)	1.80 (1.38)	0.68 (20%)	19.5 249/28	19.1 143/28	7.0 016/48
23 level (937 m)	D23-1	38.2 (0.68)	26.4 (0.41)	27.2 (0.41)	8.44 (0.30)	2.18 (0.30)	-1.65 (0.24)	0.14 (2%)	42.6 063/02	28.4 157/67	20.9 332/23
	D23-2	30.0 (1.51)	24.6 (0.92)	29.5 (0.92)	8.00 (0.67)	7.56 (0.67)	4.72 (0.53)	0.32 (5%)	45.5 239/26	28.5 114/49	18.2 345/28
30 level (1238 m)	D30-1	53.3 (1.24)	33.9 (0.76)	25.3 (0.76)	-1.13 (0.53)	3.80 (0.53)	0.58 (0.44)	0.25 (3%)	53.3 273/01	35.3 183/21	23.8 005/69
	D30-3	50.9 (0.40)	42.9 (0.24)	28.2 (0.24)	2.96 (0.17)	3.76 (0.17)	2.35 (0.14)	0.08 (1%)	52.0 249/08	42.5 158/10	27.2 017/77

(*) Orientation of principal compressive stresses (Azimuth/Dip in degrees) in the mine coordinate system (Grid north = geographic north).

(+) Average standard error for stress components in percent.

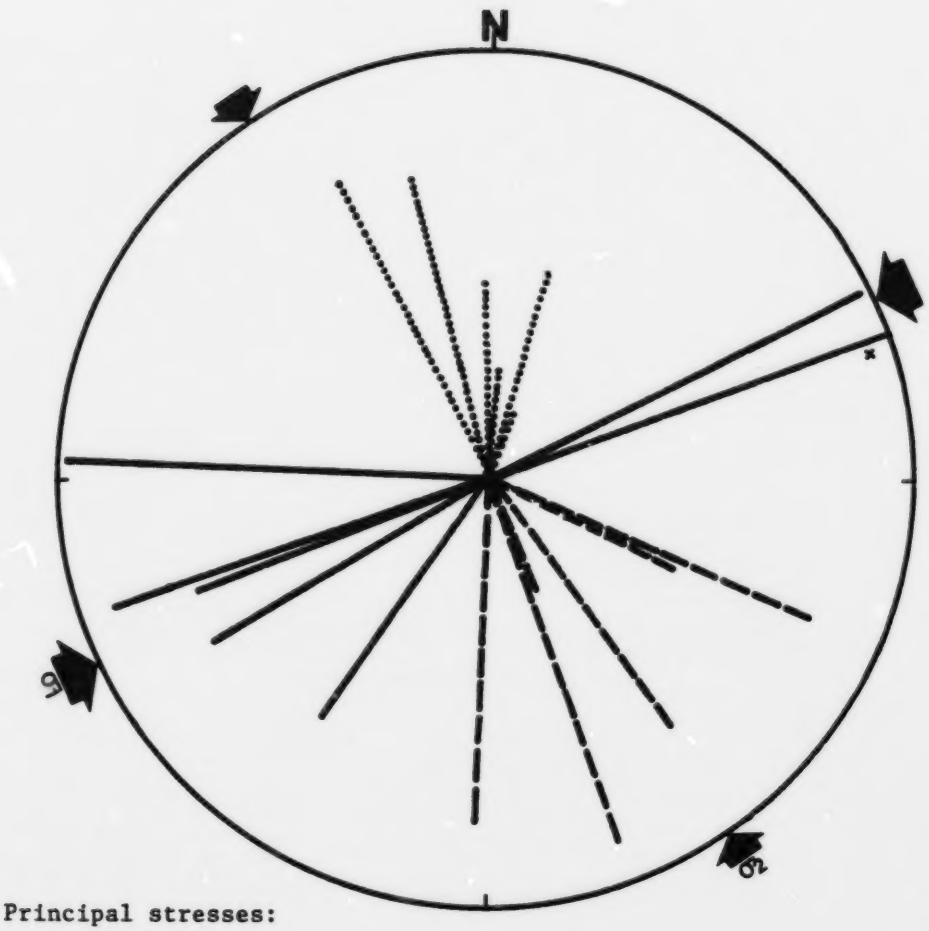

Fig. 4 - Orientation of the principal compressive stresses from Mine grid north (= geographic north) in an equal area net, lower hemisphere projection.

(x) maximum stress direction from biaxial measurements on the 2415 slope.

to the EW. and for the intermediate principal stress direction from SE to NS.

Since the maximum and the intermediate principal compressive stresses are near horizontal. these are considered as the maximum and minimum horizontal stress (σ Hmax. σ Hmin).

Based on the stress determinations. variations of horizontal stresses with depth range from 0.041 to 0.0485 MPa/m with an average of 0.0441 $\pm$ 0.0027 MPa/m for the maximum horizontal stress. and from 0.0285 to 0.0436 MPa/m with an average of 0.0336 $\pm$ 0.0054 MPa/m for the minimum horizontal stress. Horizontal stress gradients indicate that the magnitude of minimum horizontal stress reaches. on the average. about 76% (ranging from 63 to 98%) of the maximum horizontal stress. This relationship suggests an almost isotropic horizontal stress field.

The measured vertical stress varies between 0.0204 and 0.0321 MPa/m. resulting in an average gradient of 0.0274 $\pm$ 0.0042 MPa/m. The vertical components of in situ stresses approach the gravitational overburden stress on the 12 and 23 levels. On the 30 level. however. the measured vertical stress is only up to 77% of the estimated average overburden load.

Variations of the horizontal and the vertical stress as a function of depth established from the pre-mining stress components are shown in Figure 5. Data plots follow a straight line in most cases: the vertical stress values on the 30 level present the outliers.

The variation of horizontal stresses with depth fits within the range of data observed in deep hard rock mines in Northern Ontario. However, comparing the results, e.g., with the Kidd Creek Mine. located in the Timmins mining district, the average horizontal stress at Dome Mine was found to be about 70% of the measured values at Kidd Creek Mine (4,5). Figure 6 illustrates a comparison of data. The elastic modulus determined for the rocks at the stress measurement sites is on average 63.0 GPa for Dome Mine.

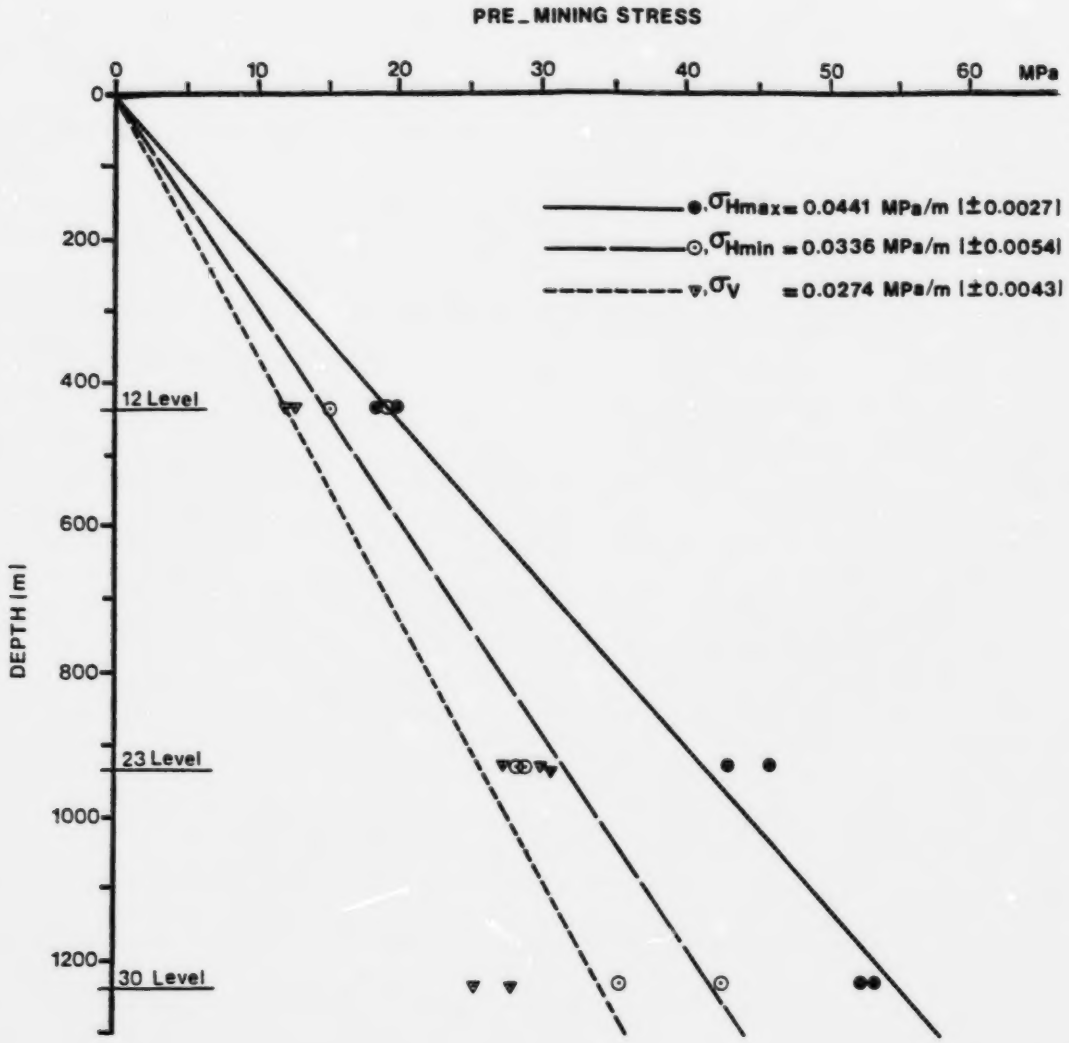

Fig. 5 - Variation of pre-mining stress components at depth between 438 to 1238 m, Dome Mine.
(▼) vertical stress measured at 2415 stope.

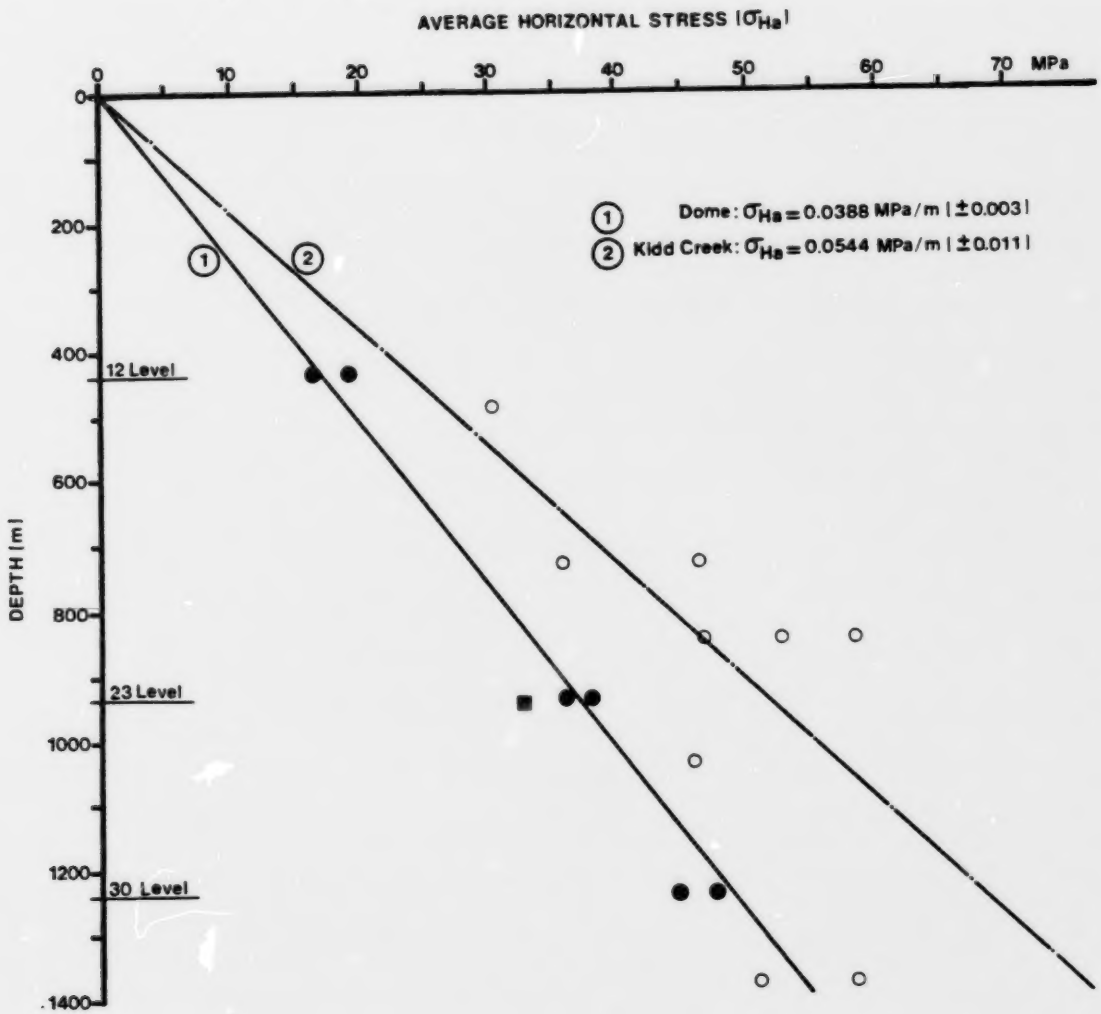

Fig. 6 - Variation of average horizontal stress with depth, a comparison of data from Dome Mine (● 12, 23 and 30 levels, ■ stope 2415) and Kidd Creek Mine (○).

and 88.0 GPa for Kidd Creek Mine. Thus, considering a similar geological structural setting, a possible explanation for the low stress field obtained at the Dome Mine is that the rock modulus is about 71% of that at the Kidd Creek Mine. In addition, it appears that the presence of stiffer rock members have contributed to a higher stress level at the Kidd Creek Mine.

From the stress determinations, ratios of measured maximum to minimum horizontal stress (σ Hmax, σ Hmin) and the horizontal stresses to vertical stress (σ_v) were as follows:

Location	σHmax/σHmin	σHmax/σ_v	σHmin/σ_v	σHa/σ_v
12 level	1.20 , 1.02	1.46 , 1.57	1.23 , 1.54	1.34 , 1.55
23 level	1.50 , 1.60	1.57 , 1.54	1.05 , 0.97	1.30 , 1.25
30 level	1.50 , 1.22	2.10 , 1.84	1.40 , 1.50	1.75 , 1.68

The calculated stress ratios indicate a wide range of variation. For stability evaluations and mine design, however, from the average stress gradients, the following pre-mining vertical as well as the horizontal stresses parallel and perpendicular to the orebodies can best be approximated as:

$$\text{Vertical stress, } \sigma_v = 0.0274\ \text{MN/m}^3 \times \text{Depth (m) in MPa}$$

$$\text{Horizontal stress, parallel} = 1.6 \times \sigma_v$$

$$\text{Horizontal stress, perpendicular} = 1.3 \times \sigma_v$$

ACKNOWLEDGEMENT

The cooperation of Dome Mines Ltd, especially L. Ng, Ground Control Engineer, is appreciated. The necessary manpower, drilling equipment and strain cells for the cooperative project were provided by Dome Mines Ltd.

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